IMPEDANCE MATCHING FOR CARRIER MULTIPLEX SYSTEMS

CONTENTS

1. GENERAL

1.1 This section is intended to provide REA borrowers, consulting engineers, contractors and other interested parties with technical information for use in the engineering and construction of REA borrowers' telephone systems. In particular, it discusses impedance matching considerations in the application of carrier multiplex systems. The impedance matching procedures apply to all types of carrier multiplex equipment whether they are to be used on wire plant or on radio.

1.2 This section is divided into three parts. Paragraph 2 is an introduction to impedance matching and covers a brief explanation of why impedance matching is necessary. Paragraphs 3 and 4 discuss the application of impedance matching at carrier and voice frequencies, respectively.

1.3 Tables 1 and 2 show typical impedances at carrier and voice frequencies. The characteristic impedance of some facilities varies widely with frequency. Therefore, the impedances shown are called typical, and are not referred to specifically as characteristic impedance.

1.4 For additional information and data on attenuation, reflection losses, etc., refer to REA TE & CM-406, "Attenuation Data," and REA TE & CM-407, "How to Make Insertion Loss Measurements."

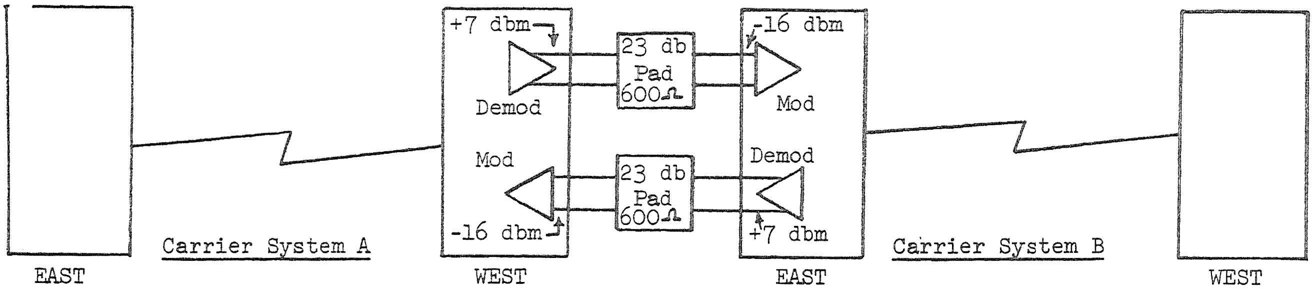
2. INTRODUCTION

2.1 Impedance matching is applied at carrier frequencies for several reasons. Briefly, a few reasons are to reduce the overall facility loss, to provide the proper impedance for filters, to provide a smooth loss slope, and to minimize crosstalk.

2.11 From a practical standpoint, when the loss of a wire line facility is to be determined, an insertion loss measurement is made. The insertion loss consists of attenuation, reflection loss and interaction loss. If the source impedance (oscillator), facility impedance, and terminating impedance are equal, there are no reflection or interaction losses; thus, the insertion loss is equal to the attenuation. One reason for impedance matching at carrier frequencies is to eliminate or reduce reflections so that the insertion loss is nearly equal to the attenuation of a facility. Interaction loss is caused by multiple reflections; thus, if there is no reflection loss, there can be no interaction loss.

2.12 The characteristic impedance and attenuation of a transmission line can be readily calculated if the resistance, inductance, conductance, capacitance and length of the line are known. If more than one type of line is used, the reflection and interaction losses can also be calculated; however, these calculations are far more complex. The data in Table 1 are based primarily on calculations, of which some have been verified by measurements.

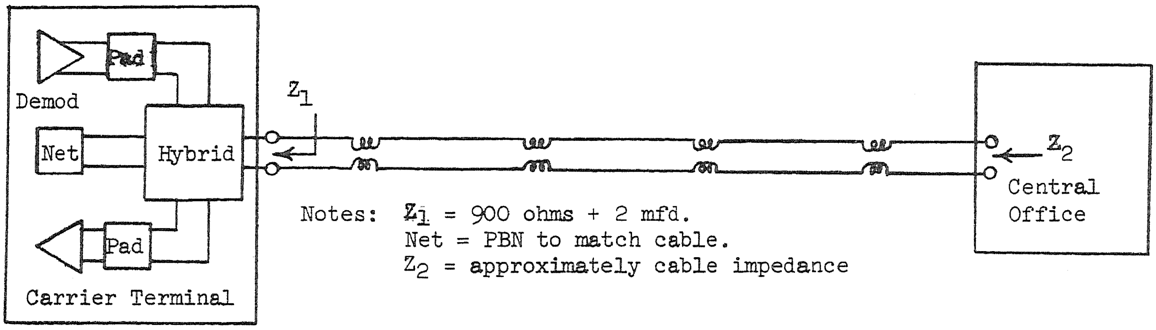
2.13 Calculations show that if an open wire carrier system at 300 kHz were applied to open wire through 500 feet of entrance cable (19, 22 or 24 gauge), the insertion loss would be 8.4 to 9.0 db higher than the attenuation of the wire and cable (Figure 1). This added loss is caused by reflections and interaction, and is relatively independent of cable gauge at the higher carrier frequencies. This added loss will cause the carrier system to operate nearer to or possibly exceed its operating limits. Even if the carrier system could operate with the additional loss, it is undesirable to have the loss rising and falling with frequency since interchannel modulation or other interfering effects may occur.



Note: Unless inband signaling is used for both systems, it will be necessary to interconnect the E & M leads of the two carrier systems.

FIGURE 3

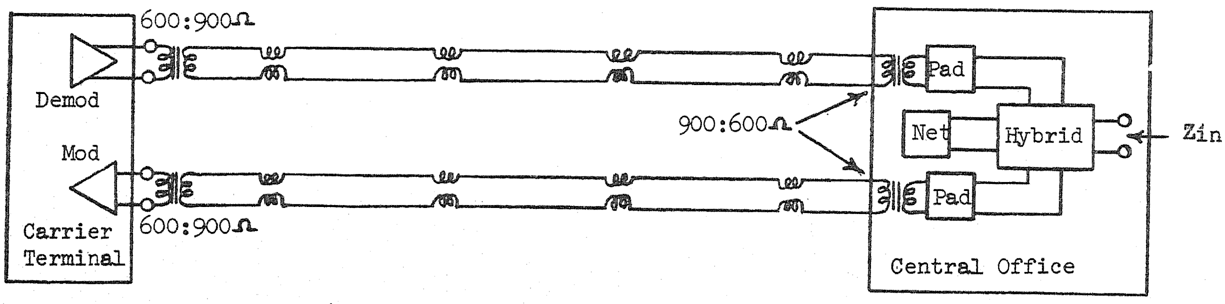
TWO CARRIER SYSTEMS CONNECTED BACK-TO-BACK



Notes: Z_1 = 900 ohms + 2 mfd.
Net = PBN to match cable.
Z_2 = approximately cable impedance

FIGURE 4

TWO-WIRE LOADED CABLE VOICE FREQUENCY EXTENSION



Notes:
1. Z_{in} and Net = 600 or 900 ohms + 2 mfd, depending on office.
2. Amplifiers may be required at the central office to help carrier offset loss.
3. Four repeating coils are required for each four-wire extension.
4. Signaling equipment located at the central office must coordinate with the carrier; this may be inband tones or d.c. signaling. Capacitors may be required with the repeating coils, depending on the signaling arrangement.

FIGURE 5

FOUR-WIRE LOADED CABLE VOICE FREQUENCY EXTENSION

2.25 When voice frequency extensions are used, there are a number of connection points and each must be carefully checked for the proper impedance. Trunk carrier voice frequency extensions are almost always loaded cable, which is approximately 900 ohms. This is covered in paragraphs 4.3 and 4.4.

2.26 Voice frequency filters are designed to connect with facilities of specific impedances and may not operate properly when used with the wrong impedance. Improperly used, the passband characteristics of filters may be changed. Also, improperly used voice frequency filters may cause excessive bridging losses at carrier frequencies.

2.27 If voice frequency impedance matching is improperly applied, poor return losses will result. Toll centers and higher class offices measure echo return loss and singing point as a quick check of the impedance of toll connecting circuits. Refer to TE & CM-925, "Transmission Measurements Involving Carrier Multiplex Equipment," for echo return loss and singing point measurements.

2.3 Open wire carrier systems are often applied to a combination of cable (near the central office) and open wire. The wire pair is frequently used for both voice (physical) and carrier frequencies. If the length of the cable is not too great, an autotransformer is used at the cable/open wire junction. The autotransformer provides impedance matching at carrier frequencies, passes d.c. for the physical circuit and may or may not provide impedance matching for the physical circuit. If the cable portion is long, a separation (low pass and high pass) filter may be provided at the cable/open wire junction. This allows the open wire portion to be used for both voice and carrier frequencies. Two cable pairs are used; one for the carrier system and one for the physical circuit. The carrier circuit can then be impedance matched and, if necessary, carrier repeaters can be used in the cable portion. The physical circuit can be loaded in the cable portion and may or may not be impedance matched.

2.4 Impedance ratio, return loss and reflection loss are all related. Return loss can be readily computed: R. L. = $20 \log \frac{Z_1 + Z_2}{Z_1 - Z_2}$. A common mismatch at voice frequencies is 600 to 900 ohms. This is an impedance ratio of 1:1.5 and yields a return loss of 14 db. The reflection loss caused by the mismatch is less than 0.2 db.

3. CARRIER FREQUENCY APPLICATION

3.1 The application of carrier frequency cable to open wire impedance matching has been simplified to the information contained in Table 1. If the reflection and interaction losses exceed 1.0 db, it is suggested that the cable/open wire junction be impedance matched. Table 1 shows the length that reflection and interaction losses equal 1.0 db with 22 gauge cable; however, reflections and interaction are approximately equal for short lengths of 19, 22 and 24 gauge cable. For high frequency carrier systems (above 200 kHz) practically everything longer than office wiring must be impedance matched. When the entrance cable is impedance matched to the open wire, the carrier terminal connected to the entrance cable must be strapped for the cable impedance. Unless instructed otherwise by the carrier manufacturer, use 135 ohms as the cable impedance and 600 ohms as the open wire impedance.

3.2 Cable impedances are very similar, regardless of gauge. In the carrier frequency range, it is not necessary to impedance match one cable gauge to another. (There may be exceptions with PCM carrier.)

3.3 When radio circuits are extended over coaxial cables or video pairs, use the impedances in Table 2 for impedance matching unless instructed otherwise by the manufacturer.

3.4 When making measurements at carrier frequencies, use impedance matching as instructed in TE & CM-925, "Transmission Measurements Involving Carrier Multiplex Equipment."

4. VOICE FREQUENCY APPLICATION

4.1 Switched Trunk Carrier

4.11 Most carrier channels are connected on a switching arrangement rather than connected to loops. This includes one end of subscriber carrier circuits and the majority of trunk carrier circuits.

4.12 If a channel is connected to central office trunk switches, its terminal impedance is either 600 or 900 ohms in series with 2 mfd. The balancing network is a compromise network equal to the terminal impedance of the channel. The return loss of a carrier channel voice frequency drop is affected by both the near end and far end four-wire termination sets. By design, the input impedance (Z_{in} of Figure 2) of the four-wire termination set should be 600 or 900 ohms in series with 2 mfd (as specified). And further, when the end office is terminated in the proper compromise network, the transhybrid loss should be sufficiently high at that end to avoid low echo return loss and singing point when measured from the toll center. When the channel is switched into another trunk or loop which meets impedance requirements, this transhybrid loss will be maintained to the degree necessary to prevent the talker at the far end from hearing echos on long toll calls.

4.13 Table 3 gives typical impedances for voice frequency terminals, facilities and offices. There may be some exceptions to the values given in the table, but unless the impedance or impedance requirements are known to be otherwise, these values should be used.

4.2 Subscriber Carrier

4.21 The voice frequency terminal impedance of both the central office and subscriber terminals of subscriber carrier are generally 900 ohms in series with 2 mfd. The balancing network is also 900 ohms in series with 2 mfd, regardless of the type or length of the voice extension. Because of the severe hybrid mismatches on revertive calls, subscriber carrier should always be set for at least 2 db loss in both directions of transmission.

4.3 Trunk Carrier Two-Wire Voice Frequency Extensions

4.31 It is highly desirable to place the carrier channel terminals where the circuits terminate and not use voice frequency extensions. Nevertheless, occasions (primarily economic) may arise when it will be necessary to use voice frequency extensions.

4.32 Trunk circuits are low loss circuits, so the voice frequency extension will most likely be loaded cable. As shown in Figure 4, Z_1 is 900 ohms in series with 2 mfd and the balancing network is a precision balancing network (PBN) to match the mid-section impedance of the loaded cable. Z_2 is approximately the loaded cable mid-section impedance, depending on the length. If the central office is a toll center, an impedance compensator should be added to the loaded cable to make Z_2 look like 900 ohms in series with 2 mfd across a wide portion of the voice frequency band; in this case the office impedance is likely to be 600 ohms, so the trunk circuit must be equipped with a 900:600 ohm repeating coil. An impedance compensator is not needed with D66 and other wideband loading systems; the mid-section impedance of a D66 loaded line is approximately 900 ohms over a wide portion of the voice frequency band.

4.33 When voice frequency extensions are used, the carrier portion may have to be set at a gain to meet the overall circuit loss requirements. If this cannot be met with the carrier, a voice frequency repeater must be used at the central office or at some intermediate point between the central office and the carrier terminal; do not use a voice frequency repeater at the carrier terminal. The carrier is treated as a hybrid type voice frequency repeater to determine loss or gain settings. Refer to the paragraph on Voice Frequency Extensions in TE & CM Section 444, "Negative Resistance and Negative Impedance Voice Frequency Repeaters and Voice Frequency Repeatered Trunks," to set the gain or loss of the carrier circuit.

4.4 Trunk Carrier Four-Wire Voice Frequency Extensions

4.41 When voice frequency extensions are required, two-wire extensions can usually meet the needs. If the loaded cable plant is old, it may have high loss and poor return loss. For these transmission reasons or for some inband signaling requirements, four-wire extensions may be more desirable than two-wire extensions. If four-wire extensions do become necessary, their exact application may vary somewhat. For simplicity, only loaded cable extensions are considered (Figure 5). The impedances of Z_{in} and network are 600 or 900 ohms in series with 2 mfd as specified for the central office. If the overall circuit loss requirements cannot be met with the available gain in the carrier, one way amplifiers may have to be placed between the hybrid and repeating coils at the office. Four repeating coils are required in this arrangement since the carrier modulator and demodulator and hybrid impedances are 600 ohms. The signaling equipment located at the central office must coordinate with the carrier; this may be inband tones or d.c. signaling over the four wires, or separate signaling leads. If inband signaling is used, it is located with the hybrid at the central office.

TABLE 1

CARRIER FREQUENCY CABLE/OPEN WIRE IMPEDANCE MATCHING

The cable/open wire junction should be impedance matched if the length of the entrance cable or cable insert exceeds that given below for the highest carrier frequency in the system. Also, the carrier terminal connected to the entrance cable should be strapped for the cable impedance.

FREQ. (kHz)	LENGTH (Ft.)	FREQ. (kHz)	LENGTH (Ft.)
50	350	200	100
75	240	250	85
100	180	300	70
112	170	350	60
150	130	400	50

TABLE 2

TYPICAL CARRIER FREQUENCY IMPEDANCES

Cable (any gauge)	135 ohms, Balanced (Note 1)
Open Wire	600 ohms, Balanced (Note 2)
Video Pair	124 ohms, Balanced
Coaxial Cable	75 ohms, Unbalanced
Radio Baseband	75 ohms, Unbalanced

Notes: 1. This ranges from about 100 to 150 ohms, depending on frequency and mutual capacitance.

2. This depends on the type of wire, spacing, etc.

TABLE 3

TYPICAL VOICE FREQUENCY IMPEDANCES

Subscriber Loop Plant	900 ohms + 2 mfd (Note 1)
Voice Frequency Extension	900 ohms + 2 mfd (Note 1)
Subscriber Carrier	900 ohms + 2 mfd
Trunk Carrier	600 or 900 ohms + 2 mfd (Note 2)
Carrier Mod or Demod	600 ohms
Class 5 Office	900 ohms + 2 mfd (Note 3)
Class 4 Office	600 ohms + 2 mfd (Note 4)

Notes: 1. Subscriber loops, voice frequency extensions and telephone sets vary widely in impedance depending on the facility, length, loading, etc. For the purposes of impedance matching, all loop plant and extensions are considered to be 900 ohms in series with 2 mfd unless specified otherwise.

2. The impedance will depend on the class of office or if a voice extension is permanently connected to the carrier.

3. This includes EAS trunks.

4. A Class 4 office is usually 600 ohms in series with 2 mfd except a crossbar tandem which is 900 ohms in series with 2 mfd.

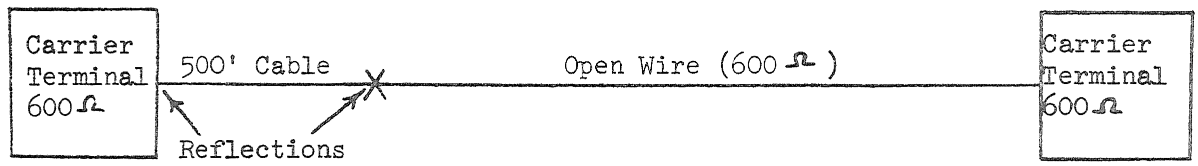
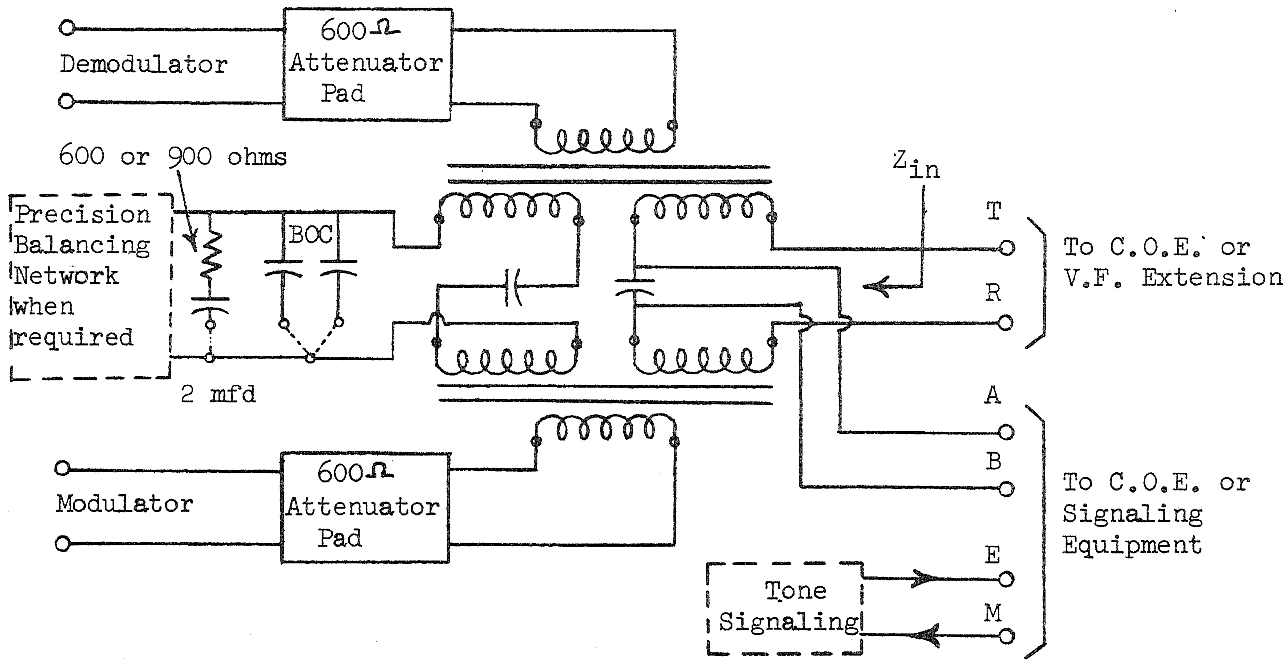


FIGURE 1

CARRIER FREQUENCY REFLECTION POINTS



Notes:
1. Strap BOC to balance out office wiring.
2. Network = 600 or 900 ohms + 2 mfd as required.
3. Network = PBN if loaded cable voice frequency extension is permanently connected.
4. Zin = 600 ohms + 2 mfd if network = 600 + 2.
5. Zin = 900 ohms + 2 mfd if network = 900 + 2 or PBN.
6. Modulator and Demodulator are 600 ohms.

FIGURE 2

TYPICAL FOUR-WIRE TERMINATION SET

2.14 Impedance matching helps to provide a smooth slope as a function of frequency which can be readily equalized by suitable networks. If there are two or more adjacent carrier systems, impedance matching also helps to reduce carrier crosstalk caused by reflections. The reflections can contribute to crosstalk in two ways: (1) unequal levels in adjacent systems and (2) reflected near-end crosstalk. (See TE & CM-463, "REA-1 Transposition System", for further information on near-end reflected crosstalk.)

2.15 In the absorption peak region of open wire, the impedance cannot be maintained at 600 ohms, but varies from very low to very high. However, the impedance of open wire is unimportant in or above the absorption peak region because it is not suitable for carrier.

2.16 Carrier frequency filters are designed to connect with facilities of given impedances and should only be used on circuits of that impedance to give proper results. Using an open wire carrier frequency filter (600 ohms) on cable (135 ohms) could alter the carrier system insertion loss or passband characteristics. Do not use open wire filters on cable or vice versa unless instructed to do so by the manufacturer. If an open wire carrier system has entrance cable longer than the lengths specified in Table 1, strap the central office terminal for the cable impedance and use impedance matching at the cable/open wire junction. The same rules apply if cable is inserted in the open wire for river crossings, etc. Some filter assemblies are equipped with repeating coils that have straps for two or more impedances.

2.17 Radio multiplex is sometimes extended from the radio terminal by coaxial cables or video pairs. The impedances of the radio terminal and coaxial cable are usually 75 ohms and will not need to be matched by external devices. The impedance of video pairs is 124 ohms and will need to be matched to the radio terminal. Wire line carrier is sometimes applied to radio also; the impedance of wire line carrier is usually 135 ohms or 600 ohms and will need to be matched to the radio terminal.

2.18 There are a number of devices available for impedance matching at carrier frequencies as described in the previous paragraphs. These are generally repeating coils of various ratios and autotransformers.

2.2 In carrier multiplex systems, impedance matching is generally applied at voice frequencies to reduce the overall facility loss, to provide the proper impedance for filters, and to improve return loss.

2.21 The voice frequency impedance matching covered in this section is primarily between the central office terminal voice frequency drop of the carrier equipment and the central office switching equipment. Voice frequency extensions of the carrier are also covered to some degree. Since repeating coils are not completely transparent in impedance, it is desirable to do all of this type of impedance matching in the hybrids (four-wire termination set) of the carrier terminal. Better terminal impedances are obtained in this manner and it reduces the chance of reversing the coil windings and getting wrong impedances. The trunk carrier specification, PE-60, requires that the proper impedance be supplied by the carrier equipment. For the purpose of this section, it is assumed that the proper impedance can be furnished by the carrier hybrid.

2.22 The two common voice frequency impedances supplied by carrier channel drops are 600 ohms or 900 ohms (in series with 2 mfd). A typical arrangement is shown in Figure 2. The modulator and demodulator of the carrier are 600 ohms. The input impedance of the carrier voice drop (Z_{in}) is either 600 or 900 ohms in series with 2 mfd. The network may be a compromise network of 600 or 900 ohms in series with 2 mfd or a precision balancing network (see paragraph 4.3). Generally the impedance of the network and voice drop will be 600 ohms if the carrier is at a toll center or higher class office and 900 ohms if the carrier is at an end office. A central office is assigned an impedance depending on its use or class. The central office is essentially transparent (has no impedance), however an impedance is assigned as an average or "nominal" impedance of the loops or trunks terminating in the office. Typical office impedances are shown in Table 3. Many central office trunk switching circuits are equipped with repeating coils for impedance matching to other components of the plant. Check that these are of the proper ratio and wired properly. The BOC (building out capacitor) is used to balance out office wiring attached to the carrier drop in large offices; this is of little use in a small office.

2.23 If the network and line (or equipment connected to the voice drop) are severely mismatched, voice frequency signals from the demodulator will cross the hybrid into the modulator and possibly cause echoes. Singing probably would not take place unless hybrids at both ends of a system were severely unbalanced. More likely the mismatch would appear as an echo to the talker at the far end of a long toll circuit operated at a low net loss. An example of this might be an operator (headset in monitor position) completing a long distance call. The answering party would hear an echo of his voice due to the poor termination of the headset.

2.24 When one type of carrier is joined to another type of carrier, the interconnection is generally a four wire back-to-back arrangement at voice frequency as shown in Figure 3. Assuming the modulator and demodulator levels are -16 and +7 dbm respectively, a 23 db attenuator pad (at 600 ohms) will be required for each direction of transmission.